

Moisture Problems in Manufactured Housing: Probable Causes and Cures

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ABSTRACT

A significant number of new manufactured houses built to HUD code and located in the hot, humid Southeast are experiencing moisture problems. Soft wallboards, buckled floors, damaged wood molding and extensive mold growth are the most common symptoms. These problems do not respond to the standard service and repair strategies for water intrusion

At the request of four manufacturers, over twenty-five such moisture damaged homes were investigated in 1999 and 2000 to determine likely causes. One time blower door, duct tightness and pressure differential measurements were performed on all homes. Field data on ambient, crawlspace, belly and house temperatures and RH were collected on a few of the homes. Recommendations and reports were prepared for the manufacturers service, production and design staff. Field repairs were performed in most of these homes.

A generalized theme existed in the houses investigated.

- Lowered air conditioner thermostat setting (typically 68-73°F), below the ambient dew point.
- Negative pressures across the envelope from high supply duct leakage (cfm @25Pa > 10 per 100 square feet of conditioned floor area), inadequate return air paths, interior door closures, exhaust fans or a combination thereof.
- Inadequate moisture removal from disconnected return ducts, fans always on (air handler or ventilation), inadequate drainage of condensate, oversized air conditioner or a combination thereof.
- Moisture diffusion from the ground into the house because of poor site drainage, inadequate crawl space ventilation, tears in the belly board, or a combination thereof.
- Vapor retarder in the wrong location i.e. vinyl or other impermeable wall or floor coverings located on the colder surfaces.

Recommended solutions provided to the manufacturers to eliminate moisture problems include:

- Maintain air conditioner thermostat above the ambient dew point (at least 75°F)
- Eliminate long term negative pressures created by air handler fans or ventilation equipment.
- Tightly seal all ductwork and provide adequate return air pathways.
- Enhance moisture removal from the conditioned space by correct sizing and maintenance of equipment
- Eliminate ground source water and provide adequate moisture barrier for the floor assembly
- If possible, remove vapor barriers located on the wrong surfaces.

Work is continuing to determine if these steps will be sufficient to prevent problems even in the presence of vapor barriers in the wrong locations for the hot, humid climates that are preferred by manufacturers and customers.

INTRODUCTION

Of the two million homes built in the U.S. in 1999, over 18.5% were built in factories to the code of the U.S. Housing and Urban Development (HUD). In 2000, one out of six new single-family housing starts were manufactured homes. Last year, the industry shipped 250,550 homes from 280 manufacturing facilities. Over 19 million people, about 8 percent of the U.S. population, live full-time in over 8 million manufactured homes (Manufactured Housing Institute 2000a). These manufactured homes are one of the most affordable single family detached housing available any where in the world, generally costing less

than \$35/ ft² plus land costs for centrally air conditioned and heated homes with built in kitchens. Available in all parts of the country, manufactured homes are more popular in the southern and western U.S. where land is still plentiful and in rural areas elsewhere.

In 1999, the U.S. Department of Energy (DOE) competitively selected the Florida Solar Energy Center (FSEC) as the Building America Industrialized Housing Partnership (BAIHP) team leader. This group's primary function is to serve the manufactured housing industry by fostering technology-based innovations that will increase energy efficiency through a systems engineering of the whole house. The systems engineering approach considers the interaction between the building site, envelope, and mechanical systems, as well as other factors. It recognizes that features of one component in the house can greatly affect others and it enables the teams, including the manufacturers and suppliers, to incorporate energy-saving strategies at no extra cost. System trade-offs, like the tightened shell that enables an engineer to recommend a smaller HVAC system, can improve the quality and performance of a home without affecting its first cost to the builders or to the consumers. The BAIHP team has three specific objectives in mind while serving the industry:

1. Cost effectively reduce the heating, cooling and hot water energy usage of industrialized housing and portable classrooms by up to 50% while enhancing indoor air quality, durability and manufacturing productivity.
2. Assist in the construction of thousands of energy efficient industrialized houses annually. This goal is accomplished by touring production facilities to try and pin-point problem areas and work with the manufacturers to resolve the problems, and provide design assistance.
3. Make our team members pleased and proud to be working with us.

Industrialized housing includes manufactured housing (built to the HUD code), modular housing (factory built housing modules assembled on site) and production housing (site built housing produced in a systematic manner). Currently, there are five HUD-code manufacturers that are BAIHP team members. These include:

- Cavalier Homes
- Clayton Homes
- Fleetwood Homes
- Palm Harbor Homes
- Southern Energy Homes

The driving force that has encouraged these builders to become team members varies from builder to builder, however there is a general underlying theme. A number of their homes built for the hot and humid climate (built according to HUD-code specifications) have experienced various degrees of building failure due to moisture. A subtask of the effort with the DOE Building America Program is entitled "Moisture Research". In this endeavor, FSEC will attempt to help team members to eliminate moisture problems plaguing HUD Code homes in the Southeast by "...conducting diagnostic tests in problem homes, fixing problem homes, evaluating the effectiveness by conducting pre/post fix short term tests, and related activities..."

THE HUD-CODE HOME

What is the difference between a manufactured home, a modular home and a panelized home? Many types of structures are built in a factory and designed for long-term residential use. Manufactured and modular home units are built in a factory, transported to the site location and installed. Panelized and pre-cut homes, essentially flat units (factory-built panels or factory-cut building materials) are transported to the site location and assembled. The major difference is that manufactured homes are federally regulated by the HUD Code under Title 24 CFR 3280. The HUD Code provides the design and construction requirements for the complete production of the entire home in the factory, with some modifications permitted for on-site completion. Modular, panelized and pre-cut homes fall under the auspice of the model building code enforced in the jurisdiction where the home will be located. These codes can include the BOCA National Building Code, the ICBO Uniform Building Code, the Southern Standard Building Code or the ICC One- and Two-Family Dwelling Code.

The Construction Process and Setup

The process of constructing a manufactured home is very different from the conventional site built home – the home is built from the inside out as it travels down an assembly line. A steel chassis is

constructed and the floor assembly (containing plumbing, wiring, and duct work) is attached. Floor coverings, interior walls, plumbing fixtures, and furnace are installed. The exterior walls with the interior finish and insulation are hoisted into place and attached to the floor. The finished ceiling assembly is then lifted from the construction jig and lowered onto the home (*figure 1*). As exterior sheathings and coverings are attached, a flurry of interior activities continues within to provide finishing touches. The newly constructed assembly is then moved to the operational test site where the various plumbing and electrical systems are checked.

Figure 2 shows a typical HUD-code home just produced leaving the factory. These homes have a permanent steel chassis with axles attached below the floor. After production the homes could travel a few hundred miles, hauled by a truck, before set up in its final location. The homes are set upon blocks or piers and the steel frame chassis is firmly anchored to the ground. A vented skirting conceals the underside of the home.

The Duct System

Manufactured homes are typically heated or cooled by a forced air system employing ductwork, which delivers hot or cold air from the air handler unit (AHU). The ductwork may be located in the attic or in the belly cavity of the home. *Figure 3* shows the ducts in the belly, supplying conditioned air to all rooms through floor vents. This is a very common and inexpensive system that is used in manufactured homes. The ducts are typically made out of aluminum or fiberglass trunk lines which supply air to the floor registers through in-line boots or through flex ducts, which terminate to perimeter registers on the floor. The most common method of sealing the various joints and connections is with a foil tape.

Multi-section homes will also have a section of the ductwork that is connected during the setup operation. A flexible duct is used to connect the supply sections together in the attic or in the crawlspace. These connections are usually made with duct tape and/or a tie strap. (Note: the authors have seen three out of twenty-five instances during the course of this project where there has been complete or nearly complete separation of this connector duct.)

The Ventilation System

All HUD-code homes are required to have a ventilation system installed. Title 24 CFR Part 3280.103b 'Light and ventilation', states that...

"Each manufactured home shall be capable of providing a minimum of 0.35 air changes per hour continuously or at an equivalent hourly average rate. The following criteria shall be adhered to.

Natural infiltration and exfiltration shall be considered as providing 0.25 air changes per hour.

The remaining ventilation capacity of 0.10-air change per hour or its hourly average equivalent shall be calculated using 0.035 cubic feet per minute per square foot of interior floor space. This ventilation capacity shall be in addition to any openable window area.

The remaining ventilation capacity may be provided by: a mechanical system, or a passive system, or a combination passive and mechanical system...."

Currently, there are two main types of ventilation systems that are employed by the manufacturing housing industry to meet the 0.10 air change per hour requirement. Both types are used in the hot and humid climate; an exhaust only system that is located in a hallway or utility room and an outside air supply system that is ducted from the roof to the return airside of the air handler fan. The exhaust ventilation system is manually controlled with a simple on-off switch. The outside air supply system is linked to the operation of the air handler and controlled with an automatic damper (if applicable).

MOISTURE PROBLEMS IN MANUFACTURED HOMES

Moisture problems are being experienced by a significant number of manufactured homes in the hot, humid climate of the Southeast United States. According to the Manufactured Housing Research Alliance (MHRA), solving moisture problems is the highest research priority of the HUD code industry. Moisture problems (*Figure 4*) include extensive mold, soft wallboards, buckled floors, damaged wood molding and trim, and high relative humidities in the home. Frequently, these homes have a high air-conditioning bill as homeowners attempt to increase comfort by lowering the thermostat temperature. (Note: each degree F drop in temperature causes an approximate 10% increase in cooling costs. The BAIHP team has

investigated over 25 problem homes and has found that the problems are caused by the following factors acting individually or in combination

- Lowered air conditioner thermostat setting (typically 68-73°F), well below the ambient dew point.
- Negative pressures across the envelope from high supply duct leakage (cfm @25Pa > 10 per 100 square feet of conditioned floor area), inadequate return air paths, interior door closures, exhaust fans or a combination thereof.
- Inadequate moisture removal from disconnected return ducts, continuous operation of air handler or exhaust fans, inadequate removal of condensate, oversized air conditioner, poorly maintained equipment or a combination thereof.
- Moisture diffusion from the ground into the house because of poor site drainage, inadequate crawl space ventilation, tears in the belly board, or a combination thereof.
- Vapor retarder in the wrong location i.e. vinyl or other impermeable wall or floor coverings.

Building Science Basics For Moisture Plagued Homes

In the hot and humid Southeastern U.S., the outside air is consistently above a dewpoint of 75°F during the summer months. If the homeowner decides to keep the interior temperature of the home below 75°F, in an effort to maintain comfort, or if an interior surface is cooled below the exterior dewpoint temperature, then when moisture-laden outside air comes into contact with cold inside surfaces, condensation occurs. If it condenses behind an impermeable surface such as vinyl flooring or vinyl wallpaper, wall board damage, floor buckling problems and mold problems can result. There are six main sources that we have seen in our investigations of ~25 problem homes with moisture damage of “unknown” causes.

Interior Temperature Below Outside Dewpoint (100% of the homes investigated)

Homeowners want to be comfortable in their homes. Thermal comfort is, in a simplified form, a function of the temperature, humidity and the physical activity of an individual (Fanger 1972). In most homes, the only “control” feature is that of the thermostat. The common perception is that lowering the temperature will provide the cooling comfort desired. The HVAC supplier/installer wants to ensure that the homeowner has a unit that is oversized to prevent callbacks of high interior temperatures or homeowner perceived excessive run-times of the air conditioning system. Oversizing can cause several problems that are detrimental to the house and occupant comfort (Karg, R. and Krigger J. 2000).

- The unit is not operating long enough to provide dehumidification. Dehumidification is accomplished by passing return air over the cooling coil.
- The interior house temperatures can be lowered to a point far below the ambient air temperature dewpoint. This can lead to condensation on interior surfaces, with its attendant material degradation and mold growth. Typical summer dewpoint temperatures range between 70 and 80 degrees F for most of the hot, humid South, especially near coastal regions.
- The oversized unit has a larger blower fan, which exacerbates duct leakage and pressure differential problems associated with the forced air system.

Negative pressures across the envelope (100% of the homes investigated)

Negative pressure is the driver that brings warm moist exterior air into the building through every crack, crevice, hole or opening that exists. The negative pressure field may encompass the entire building or there may be zones within the building that experience negative pressures created by inadequate return air paths, or interior door closures. For example, supply duct leakage and/or exhaust fans may create negative pressures in the entire house, while door closure may create negative pressure in a single room or zone of the house. It is important to note that we are talking about miniscule amounts of negative pressures – on the order of 1 to 3 Pascals. However, over time, even these tiny air pressures can lead to serious damage (Odom, 1996).

Duct leaks and return air pathways (100% of the homes investigated)

One of the biggest causes of moisture problems in manufactured homes, in hot and humid climates, is leakage from the supply ducts. In manufactured housing, the leakage is often caused by poor design and construction practices which leaves holes at the connection points of the AHU to the main trunk, the boots (or risers) to the trunk, the boots to the supply registers, end caps, cross-over duct connections and other

connection points in the duct work. When the AHU moves air, some of it leaks into the belly and eventually to the outside through tears in the belly board. This loss of air creates a negative pressure inside the house and a positive pressure in the belly as schematically shown in *figure 5*. The negative pressure draws outside or attic air into the house through the numerous cracks and crevices connecting the inside of the house to the outside or the attic. If this outside air is cold and dry, like it is in the wintertime in the Northern U.S. it will increase the heating energy use and occupant discomfort. This situation would not rot the home in this climate but it will in the hot, and humid Southern U.S..

Another aggravating factor is the lack of return air transfers when interior doors are closed. In many manufactured and site built homes there is a single return located in the main body, e.g. living room, dining room, central hallway, of the house. Air returning from individual rooms can be restricted by door closure. There is often very little area provided for return air from closable rooms; typically this pathway is the undercut at the bottom of the doors. When interior doors are closed, the bedrooms become pressurized and the main body of the house depressurizes. *Figure 6* shows the pressure differential effect of duct leakage and inadequate return air pathways. House #10 shows a positive pressure because of a disconnected main return air duct; that house operates nearly 9 Pascals positive when the air handler fan cycles on. The typical manufactured home experiences supply only type leakage as the return grill is normally located on the air handler unit.

Exhaust fans (8% of the homes investigated)

Negative pressures can also be created by the use of exhaust fans. Whole house ventilation fans installed in HUD code housing are designed to be able to continuously exhaust air from the house at a rate of at least 0.035 cubic feet per minute per square foot of interior floor space. These fans are operated by manually switching them on or off (24 CFR Part 3280.103). In our inspections, we noted only one home where the factory installed ventilation fan ran continuously – and it suffered moisture problems (house #4). Typically, this fan is not operated because of the noise that it creates. Another case (house #16) we investigated involved the installation of a dual fan window unit. The owners converted a bedroom into a pet care room and operated the window fans to control odor. Unfortunately, this not only removed the pet odor, but also depressurized the entire house by 1 Pascal. High dewpoint crawlspace air was pulled into the floor assembly through numerous penetrations in the belly board and entered the home via the plumbing, electrical and other penetrations that existed in the floor. The result was mold growth in the bathroom cabinets and the deterioration of the subfloor under the kitchen vinyl.

Inadequate moisture removal (~80% of the homes investigated)

Proper sizing, operation and maintenance of the air conditioning system is necessary to maintain interior temperatures and provide humidity control. It appears that there may be a fair degree of oversizing of equipment, though not specifically analyzed. Houses #19 and #20 are the same size, model, manufactured in the same plant and are located a short distance apart, yet one has a 4-ton air conditioning system and the other only a 2.5 ton. Both experienced problems, however the one with the larger unit had a more severe moisture problem. Based on the comments of the homeowners, some of the units have the ability to lower interior temperatures as much as 30 degrees below the ambient exterior temperature. Anecdotally, we may say that if the unit is capable of such a temperature difference, then the unit is probably oversized. An oversized unit will tend to short cycle, lowering the interior temperatures, but not able to adequately remove moisture from the air. In an effort to be comfortable, the thermostat setting is lowered.

Excessive duct system leakage also prevented adequate moisture removal from the house. The air conditioning systems were overwhelmed with ambient humidity conditions. Three houses that were investigated, had a portion of the duct system that was completely disconnected. One (house #9) had a return duct that had failed and was pulling the majority of it's air from the crawlspace. A second one (house #3) experienced a disconnected crossover supply duct. The majority of the conditioned air was lost to the attic space. The third home (house #16) had had the supply duct connecting the package air condition system to the house fall off at least three times within the first few months after being installed.

Maintenance and operation of the equipment also impacted the moisture levels within the home. The thermostat of house #4 was not operating correctly and the air handler fan was always on. Operation of the blower with supply leakage and door closure continuously placed the home in a negative pressure of -1.0 Pascal. The home had had the interior wallboard of all exterior walls replaced within the first year of

occupancy due to moisture damage. The repair crew could not find the cause of the problem, so the damaged wall was replaced, only to fail again.

Blockage in condensate drain line appears to have been the final element needed to cause catastrophic floor and wall damage to house #11. The homeowner reported that the house had operated adequately for the first year. They reportedly kept the thermostat between 78-80°F and were fairly comfortable. All at once the home felt uncomfortable and the thermostat setting was lowered to compensate, failure of materials and mold growth soon followed. During our investigation, a pie tin and plastic wrapper was found in the drain pan of the evaporator coil of the unitary system. The plastic wrapper was effectively blocking the condensate drain line causing flooding of the cabinet and recycling of the water back to the house.

Moisture diffusion through floor assembly (100% of the homes investigated)

It appears in these homes inspected that one of the moisture diffusion pathways existed between the earth and floor coverings. The typical barrier between the earth and floor coverings on a manufactured home is a “belly board”. When these belly boards have numerous penetrations or holes, free passage of both air and water vapor into the floor cavity now become an issue of concern. In many cases, standing water, or evidence thereof, existed in the crawlspaces below the belly boards. A skirting that is designed to hide the crawlspaces and provide attractive appearances then surrounds these high moisture sources. [Note: a standard for skirting ventilation of the area under the home is to provide openings that have a net area of at least one square foot for each 150 square feet (Fleetwood Homes (1999) & Palm Harbor Homes (2000))¹]. Leaving warm, moist air no choice but to rise up through the tears and other openings of the belly boards into the subfloorings. (This may be the result of air transported moisture or moisture vapor diffusion or both.) The subfloorings, composed of either plywood or wood composite materials, allow moisture vapor to pass through to the floor coverings. Carpeted surfaces offered little resistance and moisture passes into the home; vinyl floor coverings, on the other hand, are impermeable surfaces and prevent moisture intrusion. If that surface is at or below the dewpoint temperature of the crawlspace air, then condensation occurs on the underside of the impermeable flooring creating favorable environments for mold growth.

There appears to be a pattern of floor moisture/staining problems when the duct system is located overhead in the attic. Staining and warping of vinyl-covered floors has occurred in areas under the register. The areas of the vinyl covered flooring showing the worst staining were being washed by cold air from the supply registers (*figure 7 & 8*). Though measurements were not made of floor temperatures, it stands to reason that areas being washed by the supply air will tend to be cooler than those areas not washed. This cooling of the surfaces creates temperatures below the crawlspace dewpoint temperature and condensation occurs.

Vapor retarder in the wrong location (100% of the homes investigated)

The homes inspected followed the HUD code ruling on moisture vapor control as defined by section 504, which states...

3280.504 Condensation control and installation of vapor retarders.

- (a) Ceiling vapor retarders. (1) In Uo Value Zones 2 and 3, ceilings shall have a vapor retarder with a permeance of not greater than 1 perm (as measured by ASTM E-96-93 Standard Test Methods for Water Vapor Transmission of Materials) installed on the living space side of the roof cavity. (2) For manufactured homes designed for Uo Value Zone 1, the vapor retarder may be omitted.
- (b) Exterior walls. (1) Exterior walls shall have a vapor barrier not greater than 1 perm (dry cup method) installed on the living space side of the wall, or (2) Unventilated wall cavities shall have an external covering and/or sheathing which forms the pressure envelope. The covering and/or sheathing shall have a combined permeance of not less than 5.0 perms....

(Note: Uo Zone 1 includes Texas, Louisiana, Mississippi, Alabama, Georgia, South Carolina, and Florida.)

¹ The authors believe that substantially increasing skirting venting above the current standard might work to reduce moisture levels in the crawlspace.

It is common practice for the manufacturers to use a vinyl covered wallboard as the interior finished surface. This is one of the most economical finishes that can be applied and meets the vapor barrier requirement. Testing of the wallboard with the vinyl finish has been completed by others according to the ASTM E-96 standard. The results of the test showed that a 3/8" gypsum wall board laminated with 4-mil vinyl has a perm rating of 0.42 (gr./hr.-ft³-in. Hg) (Manufactured Housing Institute (2000b)).

All of the homes inspected that experienced wall board failure were vinyl coated. Typical symptoms included staining of the vinyl wallcoverings and bowing of the wallboards. Additionally, negative air pressures within the buildings were created by duct leakages, door closures or a combination of both.

The vinyl floor coverings also fall into this category. The vapor retarder is located on the interior surface. The difference is that the problem has only been seen in houses with overhead duct systems. It is believed (testing to verify is still ongoing) that the cool air from the supply registers is being blown down to the floor and is cooling the surfaces below outside air dewpoints. At this point, the solution has been to replace the current uni-directional registers with a multi-directional one. Additionally, the belly board is also sealed to prevent crawlspace vapor intrusion.

FIELD TESTING

Currently, more than 25 homes with moisture problems have been field tested by BAIHP researchers and were accompanied by the various manufacturer's service managers and other interested parties. Table 1 provides observed and measured data from several homes. The homes investigated are generally located within 25 miles of the Atlantic Ocean or Gulf of Mexico, ranging from North Carolina to Texas (*figure 9*). All of the homes have had at least one extensive changeout of moisture damaged building materials, many have had two or three.

Testing Equipment and Procedures

FSEC's testing protocol employs a battery of tests to establish the integrity of the building envelope and the duct system. These tests assist in the determination of the potential for air transported moisture problems that can cause severe damage to building components, increase energy consumption and decrease occupant comfort. Ideally, the protocol begins with three tests using a calibrated blower door and a calibrated duct tester.

The first test employs the calibrated blower door and establishes a leakage rate for the house at a specific pressure differential. This is usually expressed in cubic feet per minute at 50 Pascals (CFM50) or air changes per hour at 50 Pascals (ACH50). The next two tests establish duct system airtightness. These tests use the duct tester and yield the leakage rate of the duct system in a similar manner to the building airtightness test and are expressed in cubic feet per minute at 25 Pascals (CFM25). One test measures the total leakage from the duct system to the interior and exterior of the building (CFM25_{total}) by pressurizing the duct system to 25 Pascals. The second test measures leakage to the exterior of the building only (CFM25_{out}) by pressurizing the building and the duct system to the same pressure, removing any driving force for leakage between the building and the duct system. This results in the remaining leakage being to the outside of the building envelope. The results are airflow at 25 Pascals (cfm @ 25 Pa) and air leakage at 25 Pa normalized by the conditioned house square footage (cfm/ft² @ 25 Pa). A duct system to be considered to be "essentially leak free" in the BIAHP project when the normalized duct leakage to the outside is less than 0.03 cfm/ft² and the normalized total duct leakage is less than 0.06 cfm/ft².²

The testing protocol continued with a series of pressure differential measurements across the building envelope and across various zones within the building as defined by interior doors. A digital micromanometer with a resolution of 0.1 Pascal was used in all of the pressure differential measurements. Pressure differences may be created by either normal operation of the building's heating and cooling equipment, ventilation system or exhaust fan (including clothes dryers). Measurements were completed to

² The current industry standard for reporting duct leakage is actually a normalized value of cfm per square foot and is typically written as a percentage. This is also referred to as percent leakage to outside and percent leakage total.

$$\text{Percent Leakage Outside} = (\text{CFM25}_{\text{out}} / \text{conditioned floor area}) * 100$$

$$\text{Percent Leakage Total} = (\text{CFM25}_{\text{total}} / \text{conditioned floor area}) * 100$$

determine a magnitude and direction of flow across the envelope when the various fans operate. Interior door closure effect was also measured when the air handler fan operated. Ideally, the pressure differentials created across the building envelope and bedroom doors should be fairly close to neutral.

Results of Field Investigation

Since the beginning of the moisture investigations in the BAIHP project, it was the desire of this team to try and determine the commonality that may have existed. It appears that there is a common thread that links moisture related failures and the HUD code house of today.

There are a number of similarities that existed in the buildings that we inspected for the four manufacturer team members:

- All located in Southeast and generally located within thirty miles of a large body of water, either the Atlantic Ocean or the Gulf of Mexico.
- All had a forced air distribution system that would generally considered to be oversized. Most had duct leakage that was significant and caused the building to operate in a negative pressure.
- Most of the homeowners kept the thermostat setting between 68 and 75 degrees F in an effort to maintain comfort.
- Either a vinyl wallcovering or a vinyl floor product was associated with the moisture problem.
- All of the homes have had at least one major retrofit to repair the damaged areas. Since a cause of the problem was not located, the replaced materials were the same as those that were removed.
- Ventilation systems were usually not used or disabled.
- Typically, the master bedroom door was closed for extended periods of time. Usually, other bedroom doors were also closed – especially at night if children were present.
- The belly board (vapor retarder) contained numerous holes, penetrations and tears. The typical repair or seal was with the use of an adhesive backed cloth tape (duct tape) which had failed.

Table 1 identifies some of the characteristics of the homes and symptoms observed. In general, the investigation team was dealing with a homeowner that has a problem, sometimes severe, and data was gathered to identify the cause or source of the problem. This limited time at the house caused the focus to be on solutions and not necessarily research, though an effort was exerted to have a common data collection protocol.

SUMMARY AND DISCUSSION

The BAIHP investigation team was usually called out to homes that were not able to be solved by the normal channels that existed through the manufacturers' service departments. All of the problems that were encountered related to moisture flow in a vapor state. The causes of failure varied slightly from house to house, but in general could be categorized as a result of any or all of the following:

- manufacturing design and/or techniques,
- set-up and installation of non-factory items such as air conditioning and
- homeowner operation and maintenance

It appears that moisture damage to the building materials was a result of poor design criteria and workmanship of a building that is located in a hot and humid climate. There were some symptoms that were common in cases:

- Lowered air conditioner thermostat setting (typically 68-73°F), well below the ambient dew point.
- Negative pressures across the envelope from high supply duct leakage (cfm @25Pa > 10 per 100 square feet of conditioned floor area), inadequate return air paths, interior door closures, exhaust fans or a combination thereof.
- Inadequate moisture removal from disconnected return ducts, continuous operation of air handler or exhaust fans, inadequate removal of condensate, oversized air conditioner, poorly maintained equipment or a combination thereof.
- Moisture diffusion from the ground into the house because of poor site drainage, inadequate crawl space ventilation, tears in the belly board, or a combination thereof.

- Vapor retarder in the wrong location i.e. vinyl or other impermeable wall or floor coverings.

Recommended solutions provided to the manufacturers to eliminate moisture problems include:

- Maintain air conditioner thermostat above the ambient dew point (at least 75°F)
- Eliminate long term negative pressures created by air handler fans or ventilation equipment.
- Tightly seal all ductwork and provide adequate return air pathways.
- Enhance moisture removal from the conditioned space by correct sizing and maintenance of equipment
- Eliminate ground source water and provide adequate moisture barrier for the floor assembly
- If possible, remove vapor barriers located on the wrong surfaces.

One of our manufacturing team members has been working for the last five years in incorporating the best practice designs and techniques into their product. The result is that last year they reported no moisture vapor related failures for the first time in several years.

Work is continuing to determine if these steps will be sufficient to prevent problems even in the presence of vapor barriers in the wrong locations for the hot, humid climates that are preferred by manufacturers and customers. There is still much to be done in the area of moisture research as it relates to the interactions of buildings and its mechanical systems. Negative pressures created by mechanical systems within buildings is sometimes difficult at best to correct. Obviously, tight, well constructed duct systems with adequate return air pathways is a giant step in the right direction. There are still issues with ventilation, especially exhaust only ventilation in the hot and humid climates. Currently the HUD code does not address the type of ventilation, only that it must exist. Clothes dryers are another mechanical exhaust device that exists in a great number of homes. What is the effect of long term operation in a home where it may operate three to six hours per day? The industry, especially the HUD code manufacturing industry is slow to change – change costs money. They are looking for ways to lower manufacturing costs and still provide affordable housing.

Education. HUD code manufacturers, suppliers, retailers, setup crews, and various code officials struggle with moisture related problems, especially those problems caused by moisture in the vapor form. Good, simple and to the point training materials and courses are needed to assist in the design, construction, operation and diagnostics as it relates to moisture and moisture movement mechanisms.

The Building America Industrialized Housing Partnership will continue working with manufacturers, suppliers and building officials in an effort to provide research, training and support.

TABLES

Table 1 Collected Data From 25 HUD Code Homes With Moisture Related Problems

Identifier	Inspect Date	Location	Number Floor Sections	House Size	Ventilation type	Bowed/Buckled/Soft Walls	Mold Present	Buckled Floors under vinyl	Stains / Rust / Condensation	Interior Temperature	Problem walls vinyl covered	Tears in belly board	Ground cover	MBR door typically closed	Unsealed marriage line	Air Conditioner Tonnage	House CFM50	Duct Leak, total CFM25	House with ref to Out, ahu off (pa)	Hse-Out, ahu on, doors open (pa)	Hse-Out, MBed closed (pa)	Hse-Out, all Bed closed (pa)	MBed-LR (pa)	Bed2-LR (pa)	Bed3-LR (pa)	Comments	
1	Oct	LA	Double	3BR/2BA	V4	Y	Y	N		68-70F	Y	Y	N	Y			2453	184	0.1	-0.3	-1.4		5.2	5.1	3.6	C1,C2,C4	
2	Aug	LA	Single	1368	V4	Y	N	N		67-75F	Y	Y	Y	Y	NA	4	1789	329	-0.2	-2.6	-5.7	-5.8	6.7	1.0	3.4	C1,C2,C4	
3	Oct	TX	Double	4BR/3BA	V4	Y	Y	N			Y	Y	Y	Y	Y		3247	430	0.0	-5.6	-7.0	-8.0	8.0	3.8	4.9	C5, C6	
4	Oct	TX	Double	5BR,2BA	V4	Y	N	N		71F	Y	Y	Y	Y			1271	188	0.0	-1.0	-1.1	-2.0	4.0	2.3	2.7	C2,15,16	
5	Oct	TX	Double	3BR, 2BA	V4	Y		N		74-76F	Y	Y	Y	Y	Y		1507	204	-0.5	-0.8	-0.7	-2.5	2.8	3.0	6.6	C1,2,16	
6	Oct	NC	Double	3BR,2BA	V4	Y	N	N	N		Y	Y	Y	N			1336	162	0.0	-0.4	-0.9	-2.0	5.0	2.1	2.3	C2	
7	Aug	LA	Double	4BR/2BA	V4	N	M1	N	N	75-76	Y	Y	N	Y	Y	4	2564	285	0.0	-1.4	-1.5	-1.2	1.3	2.1	2.1	C1	
8	Jun	LA	Double	1568	V4	Y	M2,6,7	N	N	72F	Y	Y	N	N	Y		2022	314	-0.1	-1.0	-3.5	-4.3	9.0	3.0	3.0	C2,15,16	
9	Jul	FL	Double	1492	V4	N	M2	N	Y	75-80F	Y	Y	N	N	Y	3	1230	34	0.0	0.0	-2.2	-2.6	5.3	6.4	4.4	C7	
10	July	FL	Double	1492	V4	N	M2	N	Y	70-78F	Y	Y	N	N		3	1492	540	0.0	8.6	7.9	7.7				C7,C8	
11	Aug	FL	Double	2000	V4	Y	M3,4	Y	Y	73F	Y	Y	N	N		4	2000	112	0.0	0.5	-0.5	-1.2	5.5	1.4	2.4	C5	
12	Aug	FL	Single	900	V4	N	N	Y		72-80F	Y		Y	N		2.5	835	114		-0.5	-2.7	-2.7	6.5			C3,9,16	
13	Aug	FL	Single	1,080	V4	N	N	Y		72-80F	Y		Y	N		2.5				-0.2	-3.0	-3.0	10.4			C3,9,16	
14	Sep	LA	Single	1008	V5	Y	Y	N	Y	69-72F	Y	Y	Y	N	NA	3	1187	286	0.0	-2.5	-4.5	-8.5	2.2	1.5	17.0	C2,15	
15	Sep	LA	Single	1008	V5	Y	Y	N	Y	69-72F	Y	Y	Y	Y	NA	3	1425	150					4.0	9.0	4.0	3.6	C2,14,15
16	Sep	LA	Single	1008	V5	Y	Y	N	Y	69-72F	Y	Y	Y	Y	NA	3	1261	135					4.0	7.0	7.4	5.7	C2,14,15
17	Sep	LA	Double	1792	V5	Y	M1,6,7	N	Y	71F	Y	Y	N	Y	Y	4	3967	510					1.8	2.9	2.4	0.8	C15
18	Sep	LA	Double	1792	V5	Y	M1,3	N	Y	75F	Y	Y	Y	N	Y	4	3173	197					1.8	3.5	3.8	1.2	
19	Sep	FL	Double	1348	V5	Y	M1, 2	Y	Y	76F	Y	Y	N	N	Y	4	1000	158	0.0	-1.2			3.3	4.5	0.9	1.2	C2,7,16
20	Sep	FL	Double	1348	V5	Y	M1, 2	Y	Y	78-80F		Y	N	Y	Y	2.5	1007	128		1.0			2.0	6.3	4.5	3.7	C7
21	Sep	TX	Double		V4	Y	M6,7	N	Y	72-78F	Y	Y	N	Y	Y		1250	93									
22	Sep	TX	Double		V4	Y				75F	Y	Y	Y	Y	N		1423	77	0.0	-0.6			1.6	3.7	2.2	2.3	C17
23	Oct	FL	Double	1948	V4	N	M4	Y	Y	75F	N	Y	Y	N		5	1900	258	0.0	0.0			2.0	2.3	1.7	1.5	C11, C12
24	Oct	FL	Double	3BR	V4	Y	N	Y	N	77F		Y	N	N	Y	5	2496	85	0.5	-0.5			2.2	2.8	1.7	3.1	
25	Oct	FL	Double	2128	V4	Y		Y	N	67-77F	Y	Y	N	Y	Y	4	2683	185	0.0	-0.2			1.2	4.2	1.2	1.3	C3
C1: House had extra vents in w alls and/or roofs as an ill conceived moisture control measure																	Mold Present Comments:										
C2: House interior w all board w as repaired /replaced/covered before																	M1: Marriage w all										
C3: House Floors repaired/ replaced before																	M2: Under vinyl floor										
C4: House had both vinyl covered and tape and textured w all board. Problems seen only on vinyl covered exterior w alls																	M3: Closets										
C5: Very high utility bills >\$300 up to \$500/mo																	M4: Bath										
C6: Extra window a/c added as house could not be cooled																	M5: Floors										
C7: Mold on floor on cold spot directly under register																	M6: Interior Walls										
C8: Return duct disconnected at the outdoor unit!																	M7: Exterior Walls										
C9: Unoccupied home (model center)																	M8: Exterior Wall Hallway										
C10: Appears to be w inter time problem only																	M9: Switch plate off level										
C11: One room had animal care facility and large exhaust running all the time																											
C12: Supply flex fallen off from time to time																	Ventilation Comments:										
C13: Crossover not directly under furnace.																	V1: Interior ventilation intentionally disabled										
C14: Results after attempt to seal ducts using butyl foil backed tape																	V2: Mechanical attic ventilation										
C15: Standing water in crawlspace																	V3: Through wall pressure relief vents present										
C16: AHU blow er fan operates continuously																	V4: Hallway or Utility room exhaust fan										
C17: Return in utility rm dP > 5pa across utility door																	V5: POS type- deactivated										
C18: Year round moisture problem																	V6: POS type - active										
C19: * pressure measurement w / positive pressure ventilation closed																											

FIGURES



Figure 1 - Finished ceiling assembly being transferred to the house. This assembly will be fastened to the exterior walls with screws. At this point, the floors, plumbing, duct system and electrical wiring rough-ins are complete



Figure 2 - A finished house in the function test area. The plumbing and electrical systems are tested, final touch-ups are completed and the home is readied for transport.



Figure 3 - A finished metal inline duct system. Insulation on the ductwork may or may not be installed, depending on final destination of the home. This floor is currently being lowered onto the chassis



Figure 4 This home is experiencing a buckled floor problem. The subfloor is a HUD code approved composite wood product that has taken on moisture from the crawlspace.

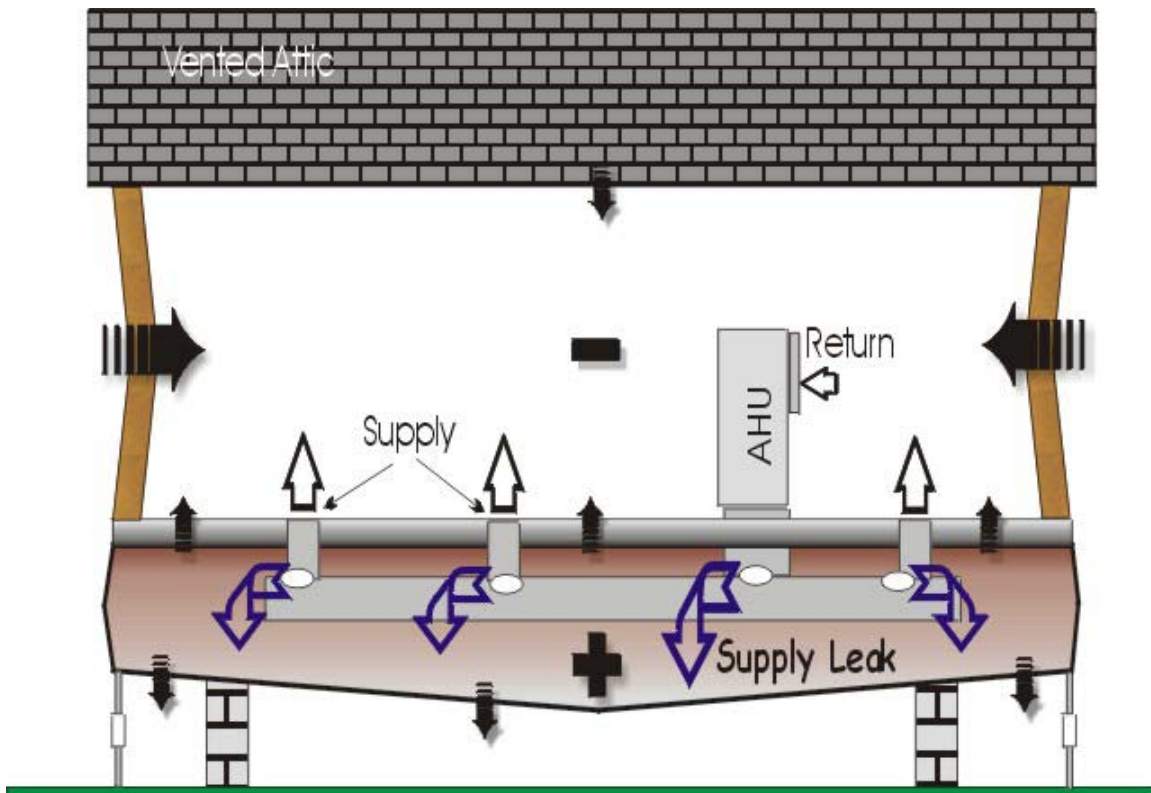


Figure 5 A typical manufactured house with an inline floor supply system loses 10-30% of the air to the “belly” of the home. There are usually numerous holes, penetrations and tears in the “belly” board, which allows free air movement between the crawlspace and the “belly”. The loss of the supply air tends to depressurize the living space above.

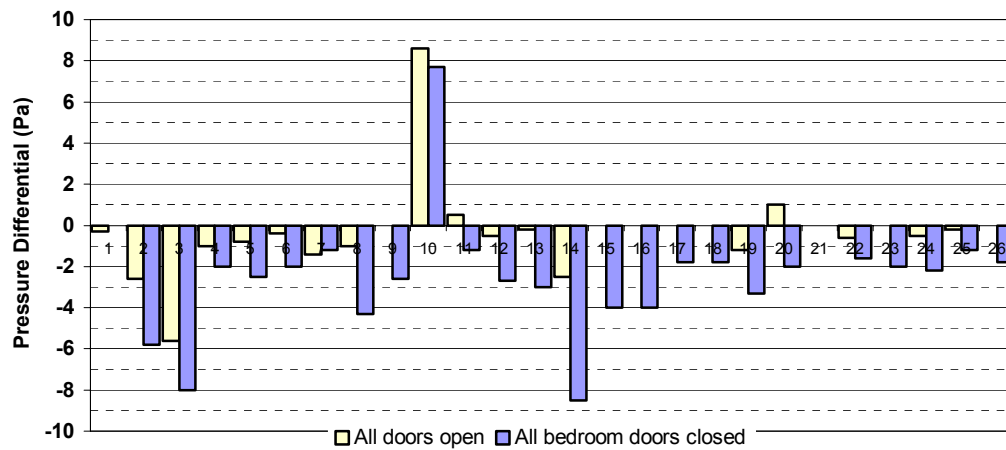


Figure 6 Pressure differential measured across the front door when the air handler fan is operating and all of the interior bedroom doors are open and then closed. The main body or area containing the central return experiences a negative pressure with reference to outside.



Figure 7 Breakfast nook with a vinyl floor covering and overhead supply register. Visible discoloration of the floor (pink spots) existed primarily in the area between the table and the cabinets on the right side of the picture. The supply register was oriented as to blow air to the outside wall.



Figure 8 The floor covering has been partial removed. The plywood flooring was wet to the touch and staining exists on much of the under side of the vinyl. The floor decking was removed to inspect the underside – it appeared dry.

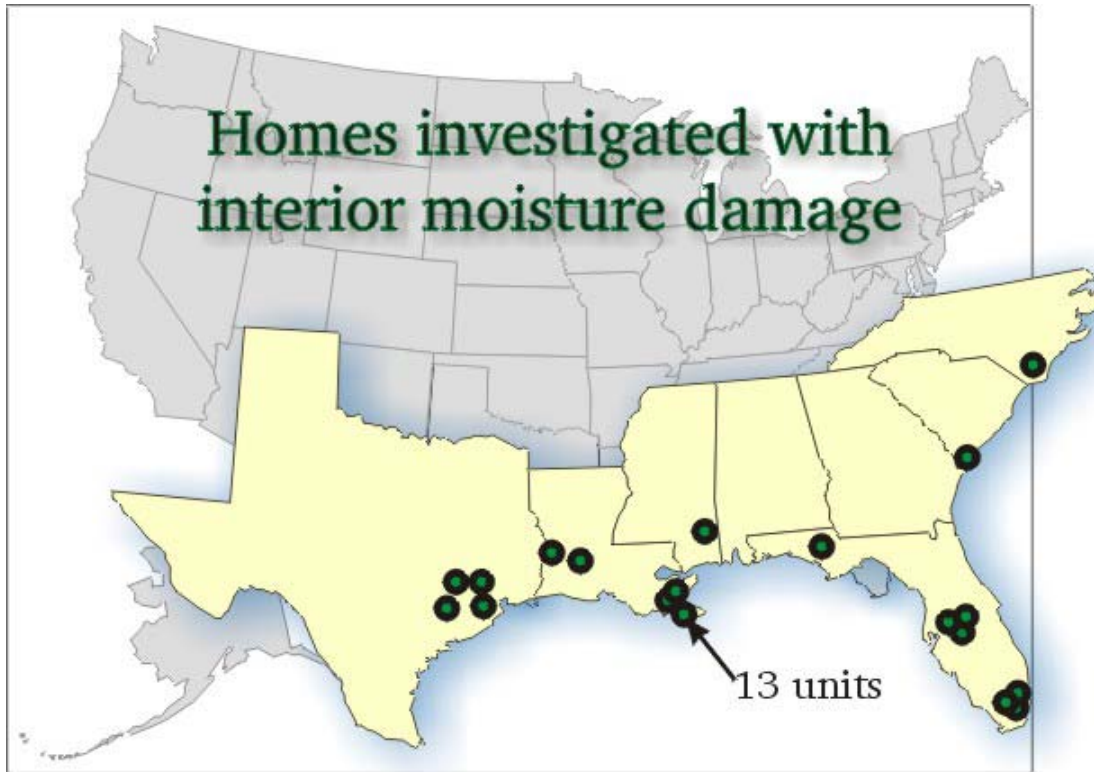


Figure 9 The southeastern portion of the United States is considered to be a hot and humid climate. The investigations that the BAIHP team has completed are indicated. Note that most are near coastal areas.

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